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ABSTRACT

Over 100 interactive computer programs for use in general and organic chemistry at the University of Texas at Austin have been prepared. The rationale for the programs is based upon the belief that computer-assisted instruction (CAI) can improve education by, among other things, freeing teachers from routine tasks, measuring entry skills, presenting appropriate material, and conducting simulations. Thus, more flexible, individualized instruction is created. Program development proceeds by breaking a course into units, specifying performance objectives, defining instructional sequences, coding the lesson into computer language and entering it into the machine, debugging it, running a pilot test, and implementing the final version. Programing strategies generally recommend pleasurable interactive sessions of from 20 to 45 minutes. Objectives are specified and then attained through tutorial drill, laboratory simulation, or synthesis programs. A control-experimental design is used for evaluation, with data being compared via techniques such as regression analysis and analysis of variance. Finally, student attitudes toward CAI are checked. (PB)

"Computer Based Instructional Techniques in Undergraduate Introductory Organic Chemistry: Rationale, Developmental Techniques, Programming Strategies and Evaluation", G. H. Culp, P. L. Stotter, J. C. Gilbert and J. J. Lagowski.

Introduction

Computer-based instructional techniques are more and more becoming a regular reference topic in reports dealing with innovative educational methods. As more and more educators become aware of the techniques of computer-based instruction, it becomes appropriate to define a representative method employed in the design, development and evaluation of this form of instructional tool. We wish to describe some of the methods and techniques that we have used in the past 5 years at the University of Texas at Austin. Although the discussion will center about general and organic chemistry, the techniques described are applicable to almost any discipline. The topics related to computer-based instruction we will discuss are 1) Rationale 2) Developmental Techniques 3) Programming Strategies and 4) Evaluation.

Rationale

Of the four topics for discussion, the rationale for using computer based instruction is perhaps the most widely known. Phrases such as "easing the problems associated with the logistics of instruction," individualized instruction," "self-paced instruction," and "relief from routine instruction for the teacher" have often been quoted in this regard. Of course, the basic rationale is one of improvement within the educational process.

All too often teachers become overly involved in attempting to help students learn in a poor environment rather than teaching; that is, they have the burden of assigning, grading and giving students feedback on homework and tests; helping students with their assignments; and conducting tutorial drill interactions. To a large extent, the computer can perform these tasks--and on an individual basis--as well or better than the instructor. This does not diminish the teacher's role in the educational process, but rather allows the teacher-student relationship to be richer in the activities teachers perform best: providing insight into difficult concepts, transmitting an understanding of abstract ideas, and inspiring students.

Computers may also be extensively used to measure entering skills, and a series of programs which may contain review materials, standard curriculum materials, and/or advanced placement materials may be prescribed. Computer programs may also simulate a variety of experiments, thus extending a student's laboratory experience to much greater depth than is usually now possible. Suitable experiments include those that require time compression/expansion, those which are too dangerous for beginning students to perform on a large scale in the real laboratory, and those which are too sophisticated and require too expensive an apparatus for wide scale use. We feel that computer-based instructional techniques are best when they a) supplement existing curricula; b) help students learn; c) help individualize instruction; and, d) are flexible in application and may be adapted to a variety of course designs.

In short, the rationale for computer based techniques is that their application has the potential of yielding a more effective and efficient instructional process.

Developmental Techniques

Program development then is keyed to identifying the areas that fall into the categories described above and applying a systems approach in development (See Fig. 1). Typically, a course is divided into units or segments; each segment is further divided into subunits, or modules; each module is then defined in terms of performance objectives, with these objectives forming the basis of the strategy for the computer program. The sequence of instruction through the program is next defined in light of the performance objectives, and the program undergoes initial construction and coding into an appropriate computer language (through this point, development of the program has been entirely on paper). Following this, the program is punched onto paper tape or computer cards and entered into the computer, debugged, then pilot tested by 2-10 volunteer students. Any necessary revision derived from the pilot testing follows, and the program is made available for full scale use by a class and evaluated in terms of student performance and attitudes. We have found that this system requires approximately 25 man-hours for development per student contact hour.

Programming Strategies

We believe the optimum program length, at least as measured by the gluteal gauge, is in the range of 20-45 minutes. Consideration of this and a personalized, informal dialog between the stu-

dent and the computer are the initial strategies incorporated into each program (See Fig. 2). The student-computer interaction should be pleasurable; one in which the student can experience a sense of comradeship and freedom between himself and this invisible, but real tutor. In this regard, options such as AID, SKIP, RESTART, or STOP provide student control of the program, thus preventing any sense of entrapment with the computer (Fig. 3). CALC is a specific option that allows the student to use the terminal as a calculator (Fig. 4). In addition, the primary objectives are stated at the beginning of each program, as shown in Fig. 5, ensuring that the student is aware what is expected in terms of his performance within the program.

Within the main body of the program, a variety of strategies may be employed in the question-answer logic. In tutorial drill programs, for example, both correct and incorrect answers may be anticipated. In the case of the former, some positive response is always given. For the latter, appropriate tutorial responses pointing out the error are given (See Figs. 6 and 7). For unanticipated incorrect answers, the format is generally to provide a strong tutorial hint for the first incorrect response, with the correct solution and/or problem set-up given following the second incorrect response (Fig. 8).

In programs involving laboratory simulation a typical sequence includes 2-5 questions concerning the prerequisites for the experiment in terms of theory, design, and data analysis. This is followed by student manipulation of various experimental parameters, along with any required tutorial assistance, and collection of data. Generally, the student then signs-off, inter-

prets his collected data and signs-on using another program that provides a step-by-step analysis of his interpretation and grades his performance (See Fig. 9).

In the synthesis programs, matricies, as shown in Fig. 10, may be constructed of various reagents and products. A product to be synthesized is presented to the student, who then selects a starting material and suggests a step-by-step sequence of reactions to achieve the synthetic goal. In most of the synthesis lessons, we allow the student to follow whatever pathway he may choose for a given problem. However, the program does allow restarts should the student encounter a dead end, and tutorial assistance is provided should the student request it (See Figs. 11 and 12). We also have synthesis programs that allow the student to work backward from the final product to a given starting material. These again are based upon a matrix of reagents and products.

At the conclusion of all programs an analysis of performance is presented to the student and, based upon an instructor-defined minimum level of achievement, either credit for the lesson is received by the student or else review work is prescribed. An example is shown in Fig. 13.

Evaluation

Evaluation of the program is a required, and indeed an exceedingly important, phase within the developmental process using the system approach. The method we use is one in which the class using the programs is designated as the experimental group and is compared with another class taught in the traditional

manner by the same instructor. Classes taught by other instructors are also included for comparison. Variables such as background abilities, as measured by the SAT-verbal and SAT-mathematics scores and chemistry placement scores for each of the two groups are considered. Standard statistical routines such as regression analysis and analysis of variance are then used to test for any significant differences between the experimental and control groups in terms of performance on examinations, laboratory work, and the semester grades. Within the experimental group, student attitudes and opinions are also gathered through fairly detailed questionnaires and evaluated in regard to the programs and design of the course.

Summary

We have detailed the process by which more than 100 successful interactive computer programs for use in general and organic chemistry have been prepared. The process is basically a version of the systems approach using an interactive debugging procedure. General programming strategies and evaluation schemes are discussed.

DEVELOPMENTAL TECHNIQUES

The System Approach

Program Definition

↓

Quantitative Performance Objectives

↓

Task Analysis and Sequence of Instruction

↓

Construction of the Program

↓

Debugging and Pilot Test

↕

Revision

↕

Class Use

↓

Evaluation

Fig. 1

ORGANIC, OCH17

WHO IS THIS?
SAMANTHA

O.K., SAMANTHA, LET'S SYNTHESIZE...

ELEMENTARY ALKENE-RELATED SYNTHESES

FIG. 2

NOW TELL ME...WHAT DO YOUR CLOSE
FRIENDS CALL YOU?
IRENE

I HEARD THEY CALLED YOU SEXY-IRENE

NOMENCLATURE...ALKANES AND CYCLOALKANES
YOU MAY COMMENT, SKIP, RECEIVE ASSISTANCE, OR STOP BY TYPING TALK, SKIP,
AID, OR STOP, RESPECTIVELY.

DO YOU WISH TO REVIEW THE RULES FOR
NAMING OPEN-CHAIN ACYCLIC ALKANES?

FIG. 3

```
CALC
I'LL KEEP IN THE CALCULATION MODE
UNTIL YOU TYPE...GO BACK...
EXPRESSION?

(760*32.5*300)/(740.5*50*18)
RESULT =          11.12
EXPRESSION?
GO BACK
```

FIG. 4

THE INTERPRETATION OF ELEMENTARY NMR SPECTRA

THIS LESSON ASSUMES YOU HAVE HAD AN INTRODUCTORY BACKGROUND IN ELEMENTARY NMR INTERPRETATIONS FROM TEXT OR LECTURE. IT CONTAINS 2 NMR INTERPRETATIONS IN WHICH I'LL GO THROUGH A STEP-BY-STEP INTERPRETATION, 2 INTERPRETATIONS AGAIN IN A STEP-WISE MANNER, BUT WHICH ALLOW YOU TO IDENTIFY THE COMPOUND AT ANY TIME, AND 1 PROBLEM IN WHICH YOU MUST PREDICT THE NMR SPECTRUM OF A GIVEN COMPOUND...

FIG. 5

```
WHAT IS THE NAME OF
  H2SO3
SULFUROUS
YOU OMITTED A WORD...ANSWER AGAIN,
PLEASE.
WHAT IS THE NAME OF
  H2SO3
SULFUROUS ACID
SWELL...
```

FIG. 6

```
      WHAT IS THE NAME OF
        CA(NO2)2
----> TELL ME.
      NO, TRY AGAIN, PLEASE...
----> CALCIUM NITRATE
      WRONG SUFFIX...TRY AGAIN, PLEASE...
      WHAT IS THE NAME OF
        CA(NO2)2
----> CALCIUM NITRITE
      YOU BET...
```

FIG. 7

THE SIGNAL AT POSITION 2.40 DELTA IS
SPLIT BY WHAT NUMBER OF ADJACENT
PROTONS?
4
YOU ARE CLOSE...
REMEMBER, N PROTONS WILL SPLIT AN
NMR SIGNAL INTO N+1 PEAKS.
THE SIGNAL AT POSITION 2.40 DELTA
IS SPLIT BY WHAT NUMBER OF ADJACENT
PROTONS?
5
ACTUALLY, THERE ARE 4 PEAK(S), THERE-
FORE, 3 ADJACENT PROTON(S).

FIG. 8

WELCOME BACK...

PLEASE ENTER YOUR ASSIGNED EXPERIMENT NUMBER? 3500
THANK YOU...
I'M VERY HAPPY TO PROVIDE YOU A CHECK OF YOUR CALCULATIONS.
THE FOLLOWING DATA IS ESSENTIAL FOR A CORRECT ANALYSIS OF
YOUR RESULTS. PLEASE SUPPLY ME WITH...

*****MILLIMOLES OF 12 FROM PLOT INTERPOIATION = ? .30

*****MILLILITERS OF CCL4 = ? 50
FINE...THIS MEANS THAT IN 50 ML OF CCL4, THERE
ARE 0.3 MMOLES 12/LITER X 50 ML X LITER/1000 ML = 0.015 MMOLES 12

IN THAT THE REACTION PRODUCES 1 MOLE 12 FOR EACH MOLE OF
H202, 0.015 MMOLES 12 REPRESENTS 0.015 MMOLES H202...

*****VOLUME OF ORIGINAL UNKNOWN SOLUTION = ? 100
GOOD...THUS THERE IS A TOTAL OF
0.015 MILLIMOLES H202 X 100 = 1.5 MILLIMOLES
OF H202 IN 100 ML OF THE UNKNOWN SOLUTION.

*****MOLECULAR WEIGHT (IN MG/MILLIMOLE) H202 = ? 34
O.K., GREAT...THUS THERE ARE
1.5 MILLIMOLES H202 X 34 MG H202/MILLIMOLE = 51 MG

***** 51 MG H202 ARE EQUIVALENT TO 0.051 GRAMS H202

SO, ALL WE NEED NOW IS......
*****WEIGHT (IN GRAMS) OF UNKNOWN SAMPLE = ? .8001
AND, ZOWIE, THE PERCENT OF H202 IN
BLEACH ACCORDING TO YOUR DATA IS
EQUAL TO 0.051 X 100 DIVIDED BY 0.8001 WHICH = 6.37 PERCENT
GOOD SHOW...JOLLY GOOD. THE ACTUAL PERCENT OF
H202 IN YOUR SAMPLE IS 7.02 PERCENT...
COME AGAIN, FRIEND...

FIG. 9

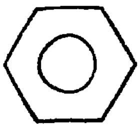
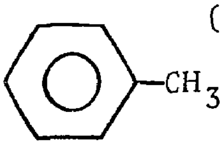
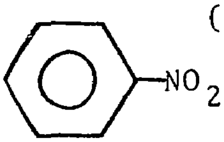
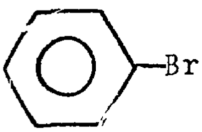
Products ↓ (R)	Reagents$^{(c)}$ → HNO_3/H_2SO4 (1)	Br_2/Fe (2)	KM_NO_4 (3)
 (1)	Reaction R=3	Reaction R=4	No Reaction
 (2)	Reaction R=5	Reaction R=6	Reaction R=7
 (3)	Reaction (very slow) R=8	No Reaction	No Reaction
 (4)	Reaction (very slow) R=9	Reaction (very slow) R=10	No Reaction
⋮	⋮	⋮	⋮

Fig. 10

```
NOW SYNTHESIZE...

            OH
           /
  HC- C- C=0
  /'  '\
HC.     .CH
  \.  ./
  HC- C
       \
        NO2

STARTING MATERIALS?
TOLUENE

REAGENT?
HNO3/H2SO4

THE MAJOR ORGANIC PRODUCT IS
     HC- CH
     /'  '\
O2N-C.     .C- CH3
     \.  ./
     HC- CH

REAGENT?
KMNO4

THE MAJOR ORGANIC PRODUCT IS
     HC- CH     OH
     /'  '\    /
O2N-C.     .C- C=0
     \.  ./
     HC- CH

REAGENT?
AID
-CH3 DIRECTS O-P, -COOH DIRECTS M...TRY NOW.
```

Fig. 11

```
REAGENT?
RESTART
STARTING MATERIALS?
TOLUENE

REAGENT?
KMNO4

THE MAJOR ORGANIC PRODUCT IS
  HC- CH     OH
  /'  '\    /
HC.     .C- C=O
  \.  ./
  HC- CH

REAGENT?
HNO3/H2SO4

THE MAJOR ORGANIC PRODUCT IS
  HC- CH     OH
  /'  '\    /
HC.     .C- C=O
  \.  ./
O2N- C- CH
THAT'S THE ONE...
```

Fig. 12

```
NOW THEN, PREDICT THE ORDER OF THE CHEMICAL SHIFTS
(UPFIELD -> DOWNFIELD) BY LETTER...E.G., BCA...
ABCD
+++
OH, JOY, WILLIAM

TO SEE THE NMR SPECTRUM OF THIS COMPOUND,
EXAMINE FIG. 10


HERE'S AN ANALYSIS OF YOUR PERFORMANCE...
TOTAL QUESTIONS = 30 TOTAL CORRECT = 27
SCORE = 90.0
TOTAL PROBLEMS = 5 TOTAL CORRECT = 5
SCORE = 100.0

I'LL ACCEPT THAT AS SATISFACTORY...GOOD WORK...


    NMR MY FRIEND, WILLIAM
    BYE-BYE...


DO YOU WISH TO CONTINUE?    NO

CC:
LOGOUT
ACCOUNT-RUN   LN-MIN   LN-COST   TM-SEC   TM-COST
CBMJ010-082       29     $0.19    6.928     $0.50
```

FIG. 13